Physical Models for Music and Animated Image: The use of CORDIS-ANIMA in ESQUISSES a Music Film by ACROE

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Abstract

The multisensorial and retroactive simulation technique of physical objects, applied to sound and animated images creation, was introduced by the ACROE in 1978 [Florens, 1978], [Cadoz, 1979], [Luciani, 1981]. Consequently, two fundamental research axes concerning the application of computer science to artistic creation have been studied: the instrumental gesture in the frame of the creator-computer relation, which gave rise to the development of Force Feedback Gestural Transducers (and recently of the Modular Force-feedback Keyboard© [Cadoz, Lisowski, Florens, 1990], and modeling and simulation of multisensorial physical objects, which gave rise to the development of the CORDIS-ANIMA© system [Cadoz, Luciani, Florens, 1990, 1993, 1994]. Thus, in the framework of computer science, artistic creation disposes of a material of a new nature. This material is based on a deep symbiosis between sound and image in the heart of phenomena and objects directly manipulated by hand and gesture. "ESQUISSES" was ACROE's first creation performed thanks to CORDIS-ANIMA material. The purpose and the structure of the work are presented here, as well as its realization processes, the specificities of the implemented models for the sound and visual production, and their symbiosis. First, the CORDIS-ANIMA principle will be recalled.

1. The retroactive multisensorial simulation with CORDIS-ANIMA

CORDIS-ANIMA enables to model and simulate natural physical objects structured in components made of homogeneous or unhomogeneous matter, with inertia, elasticity and viscosity properties and which also present some non-linear characteristics. First, it is a formalism that integrates the constraints of computer digital real-time computation: the states of physical objects are described by discrete variables evolving in discrete time steps; the components of these physical objects are chosen among a generative base of discrete components called elementary "atoms". The interactions between the object constituents are punctual (one- or multi-dimensional) and intrinsically bidirectional (supported by indissociable input/output pairs which respectively carry the mechanics intensive and extensive variables).

What is a fundamental specificity of the CORDIS-ANIMA system, is that the most elementary components can be sensorially and interactively experimented. They are simulations of elementary physical objects (such as punctual masses, springs, brakes, non-linear links), whose properties can be deduced from their standard continuous mathematical properties. The properties of complex CORDIS-ANIMA objects are the result of those of the elementary components and of the specific structure which assembles them. It is the creation of objects structure in the aim of obtaining phenomena and behaviors (sound, visual, tactile) which is the main investment of the researcher or creator using the CORDIS-ANIMA system.

The components of CORDIS-ANIMA

All the components of a CORDIS-ANIMA object are in interaction. An elementary interaction is set up between two *interaction points*, which respectively belong to the components in question. The interaction points are input/output pairs of dual physical variables (force - displacement). There are two types of interaction points: the <M> points with forces as inputs and positions as outputs and <L> points with positions as inputs and forces as outputs. An interaction is established between two components by connecting the inputs of one type of point to the outputs of the other type. Several <L> points can be connected to the same <M> point (the converse is not true).

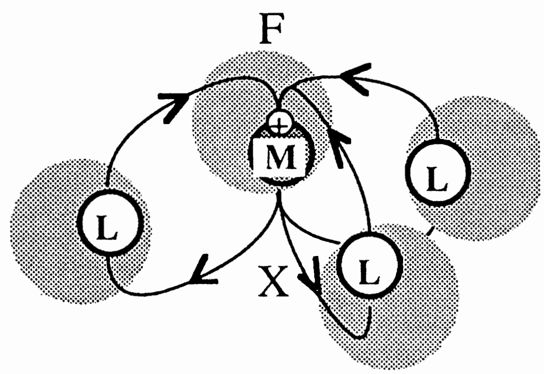

Figure 1.:The Interaction points

Two types of formal atom components can be defined: the material points <MAT> and the link elements <LIA> which make it possible to build any complex object as a network, where the junction are the <MAT> elements and the links the <LIA> elements.

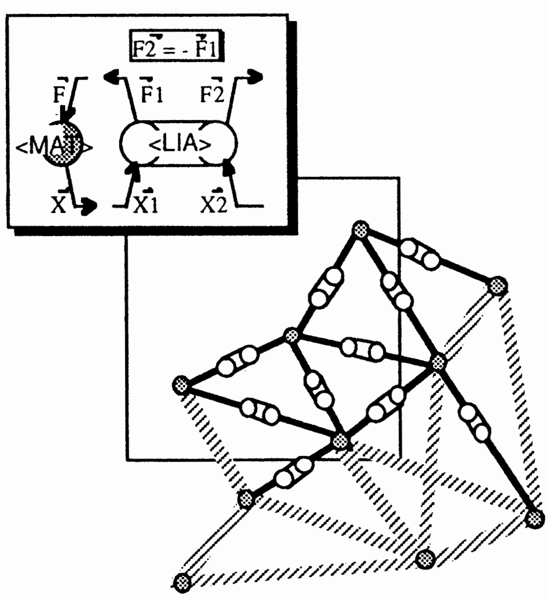

Figure 2:<MAT> and <LIA> atoms, and CORDIS-ANIMA network.

Each of the formal atom components can be processed by a specific physical simulation algorithm. The basic algorithms are those of punctual mass for the <MAT> atom, the linear visco-elastic link and the "conditional" link for the <LIA> atom.

By assembling those various elements, it is possible to describe and simulate a vast diversity of objects: vibrating structures (string, membrane ...), exciters (hammer, plectrum, reed, bow ...), articulated objects (marionette, vehicle, mechanism ...), structured objects, various materials (particle agglomerates, fluids, sands, materials of definite plasticity ...). By the resort to non-linear <LIA> elements of various natures, it is possible to describe and simulate all sorts of interactions between objects: collision and non-penetration interactions, (percussion in the case of vibrating structures, collisions in the case of visual animated objects ...), solid friction interaction, sliding, rolling, gearing, bow-string friction, etc...

By establishing a specific interaction with the operator via force feedback gestural transducers, loudspeakers and visualization screens, it is possible to act physically on the objects and to hear, see and perceive by touch, their reaction and behavior.

In the work "ESQUISSES", created for visual and acoustic presentation with no real-time performance, the gestural dimension was only exploited in the materials creation phase. The real-time aspect is not submitted in the presentation.

2. The work purpose and esthetic form.

The materials given to creators with this tool, which reconstructs the universe in its own way beginning with very small elements, cannot be of a great complexity and also, can only be understood and mastered after a fully elaborated confrontation, cohabitation and experimentation. Thus, the first purpose of the work was to get accustomed to archetypal and elementary objects and energies, but also to try to understand their secrets through their representation. Then, the general form of the work fits with a series of studies, of "*esquisses*" (drafts), where various situations have been successively explored. These "esquisses", organized in three acts suggest a progression, for objects and energy, from the most basic to the most elaborate.

First of all, this metaphorical guide comes from the distinction between the physical objects on which natural or human forces come to inscribe a movement, and these same generating forces of movements. Next, it comes from the distinction between, on one hand, the physical objects and man, irregular out of essence, and this thought process, well represented by the "number", which expresses itself through metrics and scales on time and space, and which man invents with the aid of the tools he makes.

Amongst the objects: some little structured objects such as sand or groups of particules, which have the capacity to create order, and "forms", out of a disorganized multitude; or a very structured objects constructed by man, such as mechanisms, articulated objects, instruments. Presently, a clockwork symbolizes the elaboration of temporal order from gravity.

Amongst the elements which generate movements: natural energy forces, such as gravity or winds, and human energy transmitted by gesture, face to face.

To this first metaphorical argument, it is necessary to add the opposition established, between, on the one hand, physical objects or man which are naturally irregular, and on the other hand the number. Here, on one end, the representation with the physical object simulator will be the representation of their essential and ontological irregularity; on the other end, the pure and simple use of the computer to compose acoustic instants together will be the representation of the rigour of numbers and of the matterless metrics.

Act I - Out of natural forces

In this act, the objects which produce sounds and images have been set in motion by natural forces such as gravity or wind.

Scene 1 - Dunes

(Without sound)

Sand in an hour glass, dunes in the desert.. The transition from a chaotic wind of particles towards a form misleadingly solid is probably one of the most beautiful and the most worrying which exist; with its slow evolutions, its immobility, its fluidity; with futhermore, the hardness of grains of flint and the softness of dunes which they generate.

Scene 2 - Winds

(Image and sound)

Out of the primary hostile, dry and granular universe, the wind drives towards continuity in all its states; flurries, breezes, uprisings and calm. The chants of Aeolian harp, the whistling of "la tuile aux loups", indicates a before and an after in time, indicates that something is happening, that a transition is tightening.

Scene 3 - Rains

(Image and sound)

Rain sings. Rains chatters: "On the outskirts of the copses, I no longer listen to those words which speak with human voice yet speak droplets and far aways leaves. Can you hear? Rain falls on the solitary greenery with tapping so persistent and so differing, depending on the thickness or the sparsity of the leaves Listen.... as an infinite collection of instruments under numerous fingers." - (G. D'Annunzio)

Act II - Clocks

(Image and sound)

Time is only sized by man through machines which he makes, so desperatly, to stop it or count it. As for Robinson, life mastered begins by the marking of time. This is the start of the use of natural forces to put rhythm into time and space. A real physical clock is to be found in the most far reached desire for regularity. But necessarily it starts off, fluctuates and comes to a standstil. It makes sounds, resonant or clear, never exactly alike. Just in the way that water never slides over the same pebble twice, in the same way, a pendulum or a bell hammer never finds exactly the same way.

Act III - Hyper-metric

(Without image)

A bell that is tapped, a string that is bowed, produce sounds which are themselves charged with a great internal richness. Especially when they are bodily controlled by man. But they are in essence metricsless and barless. Yet, it is for that the measure or the metric, in the musical sense of terms, arises from another intention other than that analogical intention of expression. It arises from an intention to structure. It is without doubt the first step towards this. Both concerning the metrics of a musical scaling, or the metronimy of a beat, this intention implies calculation. The computer can now produce sounds and images with natural likeness. But it remains nonetheless master in the art of calculation.

(After A. Luciani)

3. Implementation

The research carried out for many years by the ACROE team and centred on the CORDIS-ANIMA tool has played a great part in each scene and specific material of the work, as well as several recent studies, particularly centred on the subjects of the work. Moreover, each scene was the occasion of an esthetic work when creating the models, adjusting the parameters and combining them in order to express the initial metaphor as well as possible ("dunes", "wind", "rain", etc.). The mutisensorial physical model, used as a material of creation, opens an interesting problematic regarding the reference and artifice duality (cf. [Dufourt, 1981]). For instance, the idea of rain can be given by the most physically accurate (multisensorial) simulation of rain drops falling on a surface of water. It can also be obtained by the combination of physical models treated separately to obtain the rhythmic, visual or acoustic accuracy of the phenomenon, its visual poetry, its musical quality. Each of the models is physical and their combination is not only a juxtaposition, but a symbiosis between their deep variables, brought about by interaction.

We are going to develop many of these studies, and if necessary put them back in a more vast context.

3.1. CORDIS-ANIMA models for animated objects

Sand and dunes

With the participation of E. Manzotti, and A. Habibi [Habibi, Luciani, Manzotti, 1994]

Granular materials in general and sand in particular display a variety of behaviours, that are in many ways different from those of either liquids or solids. These behaviours are very partially understood. The granular material models described here, implemented and simulated according to the CORDIS-ANIMA formalism, are considered as a set of punctual masses linked together by linear or non-linear spring-damper interactions.

The models and simulations produced here account for complex phenomena such as the constitution of a pile from independant particles, as well as avalanch and internal collapse phenomena. Our approach consists of determining the minimal conditions required for the formation of a pile, for the occurrence of avalanches, collapses, arching etc. When these minimal conditions are determined, more complex models can be thought of.

A Sand Pile model - Experiments

Our aim was to construct a sand pile and to find out the necessary and sufficient conditions in which sand poured on the ground forms a pile. We assumed that the formation of a pile can be caused by the following conditions. We tested which of these conditions are necessary and which are sufficient. We know that when all four are not fulfilled, no pile is formed.

i. Dry friction between particles (caused by the non-regular shape of the particle);

ii. Dry friction between particles (caused by the material the particles are made of);

iii. Dry friction between the particles and the ground;

iv. Viscosity between particles.

We limited our tests to conditions i. iii. and iv. In other words, in our models, dry friction was only caused by the irregular shape of the particles. The point is to test each single condition while the other two are not fulfilled (for example i. true, iii. false, iv. false). If no pile is formed in either case, then no single condition is sufficient. We would have to do the tests with several conditions fulfilled. (i. true, iii. true, iv. false) etc.

The results of these experiments were quite surprising: In all cases, if a set of physical particles is poured on a rugged ground (i.e. with dry friction with the particles) a pile is formed. This was carried out with smooth particles and it holds even when the particles are perfectly round and non-viscous. As a consequence, friction between the particles and the ground is a sufficient condition for the formation of sand piles.

In all cases if a set of physical particles is poured on a smooth ground (i.e. with no friction with the particles) no pile is formed. This holds even for viscous particles with complex shapes. This means that friction between the particles and the ground is also a necessary condition for the formation of a pile.

Finally we end up with a very simple model: round, smooth, non-viscous, non-cohesive particles with simple repulsive interactions poured on a rugged ground. But this very simple model accounts for very complex phenomena: we observed stable shapes i.e. piles and stable cavities inside the piles. Dynamically we observed avalanches and internal collapses revealing that the force distribution within the pile is basically heterogeneous. Pressure and constraints in these simulated piles propagate along specific lines, through specific grains as in real granular materials.

Different values of stiffness and different grain sizes lead to different repose slopes and different dynamic behaviours. But one important consequence of these experiments is that a necessary and sufficient condition for the formation of piles of granular materials is friction between the particles and the ground. This conclusion is all the more important that such a result could only be achieved by simulation. In the real world, such a condition cannot be tested since friction between particles and the ground cannot be eliminated.

These results and properties were exploited in the scenes "dunes" of the work. The sands particles submitted to a horizontal force weekly fluctuating, gather together and form piles on fixed obstacles placed on their way.

Winds

With the participation of B. Chanclou [Chanclou, 1994].

The wind is presented in various studies as a velocity field in which visible elements (particles) are evolving. The velocity field is constituted of two components; the first one is an addition of primitives: uniform, sink, source and vortex. The second one is a filtered random velocity field; the characteristics of the filter are chosen in accordance with the phenomenon reproduced. The approach developed in our context is totally different and leans on the particle physics, implemented in the CORDIS-ANIMA system.

Wind particles are evolving in a force field. In here, the difference of pressure generating the movement in fluid mechanics, is constituted by this force, called Fmouvt and which is applied to each particle. Moreover, the environment where the particles are evolving is viscous. Thus, the particles velocity is function of the balance between the force generating the movement, and the one due to the environment viscosity.

The particles evolve at various velocities, depending on their environment viscosity. Yet, since the particles are independant of each other, they always move on straight lines in the direction of the average force of the wind. To produce turbulences, it is necessary to introduce an interaction between the particles, so as to cause a relative motion. Two masses rigidly connected form a couple of points, able to rotate around the centre of gravity when a force is applied to one of the two elements. The couple of rigid points is obviously not a solution, since the particles would form a rigid group. Moreover, the interactions between the particles must have a threshold. Indeed, distant particles do not interact.

This led us to choose an interaction of variable viscosity, depending on the distance between the connected masses. This interaction offers the two desired advantages: first a reaction against movements between the particles and then the interaction threshold.

The viscous interaction between particles tends to maintain them constantly at the same distance from each other. Then, in the case of two particles interacting, if one of them is slowed down by a greater environment viscosity, the distance between the particles increases. As a result, the viscous interaction tends to bring both particles together. The resulting motion is the translation-rotation of the couple of points.

Notice that, to generate the rotation movement of the couple of points, the forces generated by the viscous interaction have to be great enough. Thus, the viscosity between particles must necessarily be greater than the environment viscosity. Otherwise, the environment viscosity forces are higher than those of the cohesion of the couple of points, and the latter breaks up.

The example given for a couple of points is valid for any group of points in interaction. If a part of the group is slowed down by a greater environment viscosity, it generates a rotational motion. With this method, we were able to obtain turbulence effects easily.

In the scene "Wind", this model was implemented to create the movement. Yet, the model used for the particles motion and the one used to generate the acoustic flow are totally independant. The acoustic model, called "poutre qui chante" ("the singing beam") is the result of the study of sustained vibrating structures. The model disposes of morphological properties common to the properties of the wind particles and their turbulence. We mastered the sound "turbulences" so that they would follow the turbulences of the wind particles images. The rhythm of the visible particles was used as a score for the creation of the "the singing beam".

Rains

This study was carried out by Jean-Loup Florens, Claude Cadoz and Annie Luciani.

The approach developed in this scene is of a totally different nature. The point is to evoke rain drops falling on a surface of water, thanks to physical models producing sounds and images. This required three models in interaction: first a model for the determination of the instants of drop impacts, which also enables the control of their density and rarefaction; another model for the production of percussion sounds distributed on a specific scope, using the previous impact instants; finally a third model for the production and visualization of waves on the surface of the water. This model uses the engraved screen process that will be described further.

The drop impacts were realized by a set of particles subject to gravity and falling on a "comb" composed of mass-spring-damper cells. This comb is characterized by a specific width. The regular interval between the cells does not prevent particles from possibly passing through the comb without any percussion. The particles arriving on the comb can either pass through, or, collide with a cell, bounce and remain within the vertical field containing the comb, or finally collide, bounce and leave this field. When the particles have gone through the comb, they are absorbed and regenerated on the top. In the beginning, the particles are released within a very short band all inside the width of the comb. In this situation, the number of percussions is maximal. But gradually the particles bounce out of the field and result in a progressive dispersion and rarefication. In the end only a few particles are left in the field and produce the last few impacts.

This process contains a module that detects each drop-cell impact. The recorded information consist of: the date of the impact, its intensity, the number of the drop and the number of the collided cell. Then, these informations are used as the exciter input (percussions) of an instrument composed of several elementary vibrating structures with different tunings so that the pitches remain within a specific (narrow) scope.

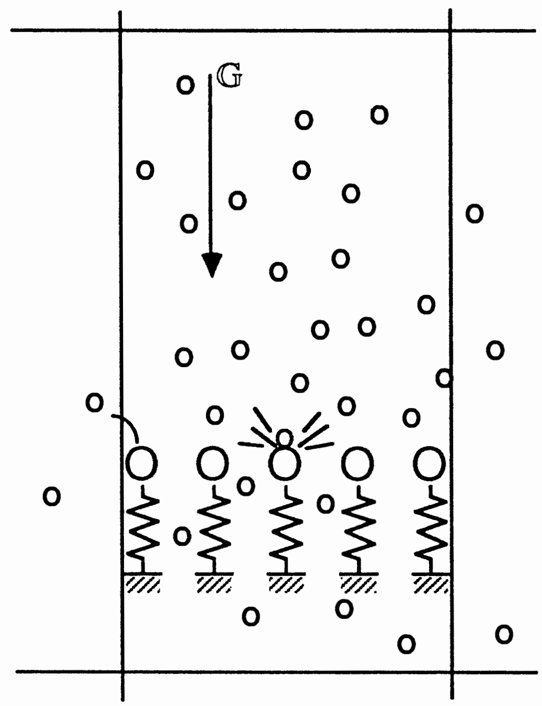

Figure 3

The clockwork

This study was carried out with the participation of J. Nouiri [Nouiri, Cadoz, Luciani 1994].This scene was realized from a wholly simulated clockwork with all the functional components of its mechanism. In the sequel, we present the mechanism of a real clockwork and the simulation of the modeled clockwork presented in ESQUISSES.

Clocks are used for the measure of time. The time base is generated by the oscillation of a *pendulum* in interaction with a source of energy necessary for the maintaining of the oscillations. The supply of kinetic energy of the oscillating element is provided by the transformation of either the elastic potencial energy of a spring (strained during an initial rewinding) or a gravitational potential energy of a weight. This energy must be let out regularly. This is done by the ***regulator*** or *escapement/damper* mechanism. On the one hand, this mechanism provides the energy impulse necessary to compensate for the attenuation of the oscillation caused by mechanical imperfection and

a damping environment, and on the other hand, it inhibates the energy supply until to the next sequence. This is the level where time regulation is carried out. Time display is carried out by visual systems (hands) or "sound" systems (gongs).
A clockwork is composed of:
(i) An oscillating mechanism that generates the time base: the counter
(ii) A source of energy necessary for the maintaining a stable movement: the motor
(iii) A mechanism that regulates energy and time: the regulator.
(iv) A time display system

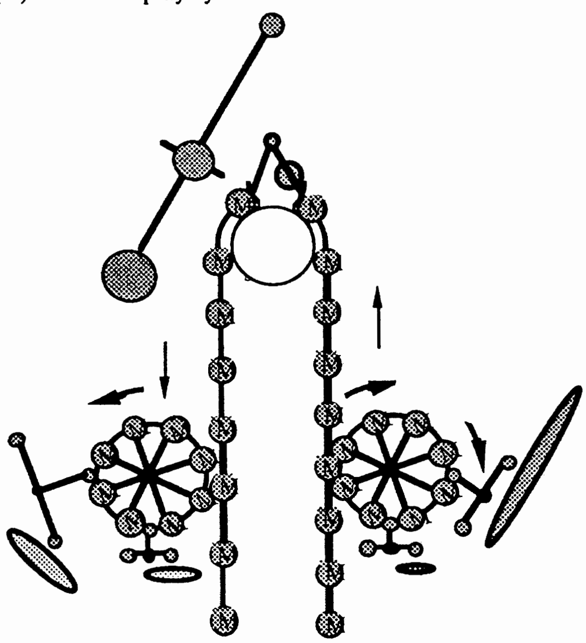

Figure 4. A sketch of the whole clockwork mechanism

The oscillating elemen is a pendulum system with three mass elements: one pivot, one central point where kinetic energy from the motor is received and a third point representing the inertia and the weight of the pendulum. This structure is reinforced by two lateral mass elements which provide the stability of the model's shape and guarantee maximum rigidity for the whole structure.

The motor element is modelled as a fine chain of masses guided by a round sliding channel. The maximal duration of the functioning is determined by the total number of masses on the chain (See Figure 4). The movement of the pendulum is maintained by kinetic energy transfer from the masses to the pendulum, through collisions, firstly between the falling masses of the chain and the escapement/damper mechanism, and then between this mechanism and the pendulum.

The escapement / damper mechanism is the major piece of the model. Three vital functions are concentrated in this single mechanism, in order to simplify the determination of the parameters of the model and the final adjustments. The model of the constructed model comprises three parts. The first part stops the falling chain. It is called the *damper*. The second part transmits the kinetic energy of the masses to the mechanism. It is called the *escapement*. The third part transmits the kinetic energy acquired during the escapement, to the pendulum. The first parts are constructed by a set of mass elements arranged so as to obtain rigid curve shapes in order to facilitate collision and damping with the masses of the chain.

To display the counter of th time, we have also imagined sound displays. They are represented by a set of gong models (4 in the case of this model). These gongs are struck by hammers moved by the falling masses of the chain through a gear system. (See Figure 4).

3.2. CORDIS-ANIMA models for the sound

CORDIS enables to simulate physical instruments. The latter are modeled at two levels: the level of their macro-structure made of a channel from the gesture to the acoustic phenomenon (gesture - exciter - vibrating structure - local environment - global environment - acoustic phenomenon), and the level of their micro-structure, i.e. the physical composition of each of the macro-structure components. In various studies recently conducted at the ACROE, a special attention was put on the modelisation of vibrating structures and their mode of excitation.

Spirals

This study was carried out with the participation of Eric Incerti (PhD student at the ACROE). By nature, CORDIS leads to conceive the vibrating structure (VS) as an assembling of ponctual masses, springs and brakes. Two categories of datas allow to characterize a vibrating structure: the topological description of the Masse-Spring-Friction network , and the parameters value (inertias, stiffness, viscosities). A systematic study, driven by Eric Incerti on the vibrating structures topologies, proved the interest of structures shaped in "simple" or "double" spiral (Figure 5 and 6).

The parameters of these structures are: their size (number of masses), the ratio number of turns vs number of spokes, as well as physical parameters (inertia, stiffness, viscosity). By modifying these various parameters and the exciting points, a great variety of realistic sounds is obtainable, from the bell to gongs and convincing approach of cymbal sounds ...

The first exciting mode used corresponds to the instant excitation. Two complementary modes were developed: pinching and percussion [Simonnet, 1993], [Eremeef, 1993].

The first is modeled thanks to a CORDIS conditionnal link, which allows to move one or more points of the structure out of the balance position, and then to release the link when the tensed force exceeds a predetermined threshold. The second assumes a minimal modelisation of a striker, made of one or several masses carried along by a function of gestural command, and linked at the structure exitation points by an interaction conditionnal link.

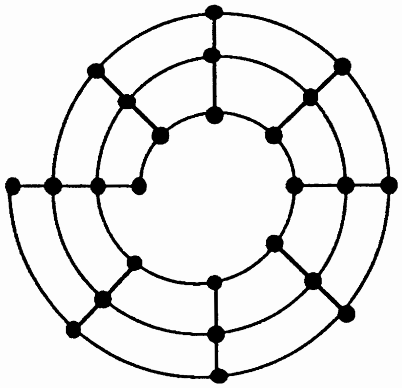

Figure 5. Simple spiral

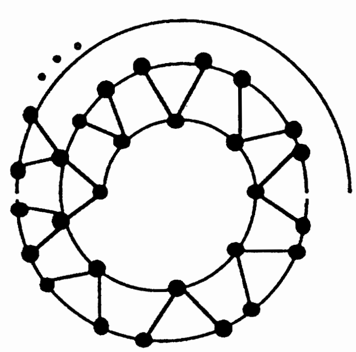

Figure 6. Double spirale

Singing beam

This study was carried out with the participation of Jérome Alphonse and Régis Msallam.

Another series of studies following those on the modelling of bowed strings thanks to CORDIS-ANIMA [Florens & Cadoz, 1990] was more generally connected to the type of nonlinearities to implement in the conditional links in CORDIS in order to obtain a sustained vibration. The studies of Jérôme Alphonse and Régis Msallam [Alphonse, 1993], [Msallam, 1993] have led to a particular model with two relevant control parameters: the velocity of the bow and its pressure on the excited structure. In particular there is a threshold pressure above which sustained excitation (with periodic vibration) can be obtained and below which only certain partials (corresponding to the eigen modes of the structure) can be excited. In the second situation, very small pressure variations produce rapid changes in the prompted partials. When the pressure fonction is specified, the resulting sounds present very rich characters of pitch evolution.

Among the excited structures in this way, one of them modelling a two dimensional beam produced very fine results used in the scene "wind". The sound gusts synchronized with the particle wind correspond to instants when pressure gets beyond the threshold mentioned above.

Modal Synthesis

Some of the sounds used in the piece were made thanks to the modal synthesis technique describe by Pirouz Djoharian. This technic is described elsewhere [Djoharian, 1990, 1992, 1993, 1994].

The musical scales and argument in Act III

From Claude Cadoz.

In Act III the sounds previously computed by CORDIS in accordance with the models mentioned above were assembled by a classic digital sound edition tool (Protools© software from Digidesign). Two guides were used for the construction. The fist is the simple musical argument of chimes and various clockwork sounds (tic-tac, etc.). That enabed us to use the whole range of realistic sounds obtained by the spiral models. The second is the resort to pitch scales deduced from the spectral properties of each sound. A single pitch is common to all sounds (the A). Thus, each vibrating structure used in the piece has its own scale built by bringing inside the octave interval the firts partials appearing in the structure.

3.3. Visualisation

We have developped a specific visualisation method, designed to be well adapted for the visualization of very deformable objects such as smoke, fire, liquid surfaces and sand. It is called the Engraved Screen. The engraved screen is a physically simulated deformable surface composed of a great number of discrete mass elements (up to 400 000). The objects to be visualized are put against this deformable surface and act as chisels in a sort of dynamic bas-relief sculpture. If the screen has elastic properties, the traces disappear more or less rapidly according to the physical parameters of the screen. Furthermore, different values of cohesion between the masses of the screen produce surfaces that resemble rather a piece of wood or an elastic blanket.

This physical simulated screen has geometrical and physical properties:
1. Grain and texture. The geometrical and physical properties of the 3D pixel that is, the arrangement of the pins on the surface of the screen, the shape and the size of each pin and the lighting would model the textured grain of the support.
2. Remanence. The drawer's paper as well as the photographer's film are a sort of permanent memory. With the use of computer simulation, other supports can be envisaged for which the

traces' lifetime would be a parameter. More or less fleeting traces as on paper, on sand, or even on liquid surfaces. The remanence of the trace can be controlled by the attribution of a physical behavior to the 3D pixels.
3. Dynamic behavior. By establishing physical interactions between the simulated 3D pixels, it becomes possible to model dynamic properties such as diffusion, absorption, (blotting paper effect, static blur effect) delayed impression (development effect) and propagation effect (wake effect, dynamic blur effect)
4. Visual properties. When the pins are all pushed in, they have no shadow on the screen. Thus the screen appears as a white surface. When they are all out, the shadows cover the screen and it appears as a black suface, and when a marker object runs over the screen, pushing more or less the pins underneath, the resulting image with its gradations between black and white renders the shape of the marker.

For the simple observation of the dynamic of physical objects, a rather small number of points (300 to 1500) seem to be sufficient, even for complex phenomena such as piling, avalanches and internal collapses. But for visualization, especially for artistic purposes, a far higher resolution is required. The Engraved Screen plays in his case the role of a physically - based interpolating shape method to generate, from a few numbers of points in the underlying model, the sufficient number of points (the pixels) for an accurate and fine visualisation.

English translation by Claude UHL and Arash Habibi (ACROE).

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